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HAWAII INSTITUTE OF GEOPHYSICS
UNIVERSITY OF HAWAII

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ABSTRACT

Five sources of underwater sound having volcanic characteristics have been located in the Pacific Ocean by means of the Pacific Missile Range sofar hydrophone network. Two are in the Mariana Islands, one in the Nanpo Shoto, one in the Aleutian Islands, and one at the southeast end of the Austral Seamounts The sounds range in duration from a few seconds (explosive) to weeks (periodic low rumblings). Sonagrams of some of these events show multiple bands as do those of underwater explosions.

CONTENTS

INTRODUCTION

Although it was early predicted that the deep-ocean sound channel would be used to detect and locate submarine volcanic eruptions, no such program has been deliberately pursued over an extensive region. The results presented here were incidental to a long-term study of earthquake T phases in the Pacific Ocean. These results demonstrate that the continuous monitoring of a widespread sofar hydrophone network can provide early detection and location of submarine eruptions throughout broad ocean regions.

The continuous or repetitive nature of a volcanic eruption is a criterion by which it may be distinguished from an artificial explosion. However this same characteristic provides a background against which the detection of an artificial explosion is rendered more difficult. The problem is further complicated by the fact that some submarine volcanic eruptions have multiple-band spectra, in common with non-venting submarine explosions.

BACKGROUND

Ewing et al. (1946) speculated that some underwater sounds heard while monitoring for shots in the Atlantic Ocean might be from submarine volcanic activity. They predicted that an application of the sofar channel would be the detection and location of submarine volcanoes. Dietz and Sheehy (1954) studied underwater sound records of the 1952 eruption at Myojin Reef near Bayonnaise Rocks in the Nanpo Shoto. The records were made at U. S. Navy Sofar Stations in California. They detected more than a hundred explosions. Sofar station personnel reported that signals audible over the station loudspeaker resembled closely-spaced distant explosions.

Snodgrass and Richards (1956) recorded underwater sound at Bárcena Volcano on San Benedicto Island, Mexico. Using air-dropped sonobuoys they tape-recorded rumbles with a pitch of about 125 Hz as well as hissing noises. The latter were attributed to the quenching of hot lava by the sea. A sound-spectrum analysis of a rumble from Bárcena showed 50 Hz harmonics between 50 and 300 Hz. Richards (1963) reviewed volcanic sound recordings, both air-borne and water-borne, for the decade 1950 to 1960. He listed sounds characteristic of the four classifications of volcanic activity. Characteristic of explosive activity is a fundamental frequency with harmonic progressions (Strombolian and Vulcanian). Richards ascribed the banded spectra to resonance within an open space in the vent.

Kibblewhite (1966) discovered an underwater volcano 150 miles northeast of North Island, New Zealand, by his study of records

from hydrophones located just northeast of the island. He described a continuous activity, which was audible when it was at a high level, as a low rumbling or a booming of drums. Frequency-versus-time sonagrams of this activity showed a range from below 10 up to 70 Hz when at low level and up to 130 Hz or more when at high level. Hours-long intervals of cyclic rising and falling of sound level, commonly with a period of 3 to 5 minutes, were observed. Multiple-band spectra were associated with strong cycling. Large isolated pulses of a few seconds duration were also observed, usually associated with the continuous activity.

Shepherd and Robson (1967) studied a twenty-minute event whose computed source point and origin time coincided with earth tremors felt in the vicinity of the submarine volcano Kick-'em-Jenny which lies just north of Grenada in the Lesser Antilles. The principal recording seismometers were located on six nearby islands. Noting the absence of P and S phases and the long duration of the T, they suggest that the source was not an earthquake, but that the sound was generated in the water, or at a shallow depth beneath the ocean floor, by a series of explosions--possibly by generation and collapse of steam bubbles.

SUBMARINE SOUND SOURCES

The Hawaii Institute of Geophysics has been routinely computing and publishing the source data of Pacific T phases since 1964 (Johnson, 1966). Data for this program are continuous chart recordings of sound-power level made at seven widely spaced sofar-depth hydrophone installations in the North Pacific. The charts are viewed simultaneously as they are rolled across a large X-Y chart reader table where arrival times and power levels are fed to an on-line computer.

The continuous scrutiny of hydrophone records required by the source location program has provided a familiarity which has enabled us to detect deviations from the normal pattern of explosions, ship noise, animal noise, hydrophone cable strumming, and earthquake T phases. Five such deviations in the past two years we ascribe to submarine volcanic activity. They are listed in Table 1 and charted in Figure 1.

TORI SHIMA

On 12 November 1965 an outburst of noise which resembled a swarm of shallow earthquakes or muffled explosions, occurring at the rate of one or more a minute and rising out of a continuous background rumble, was recorded at six of the seven stations (Fig. 2). The path to the remaining station was obstructed.

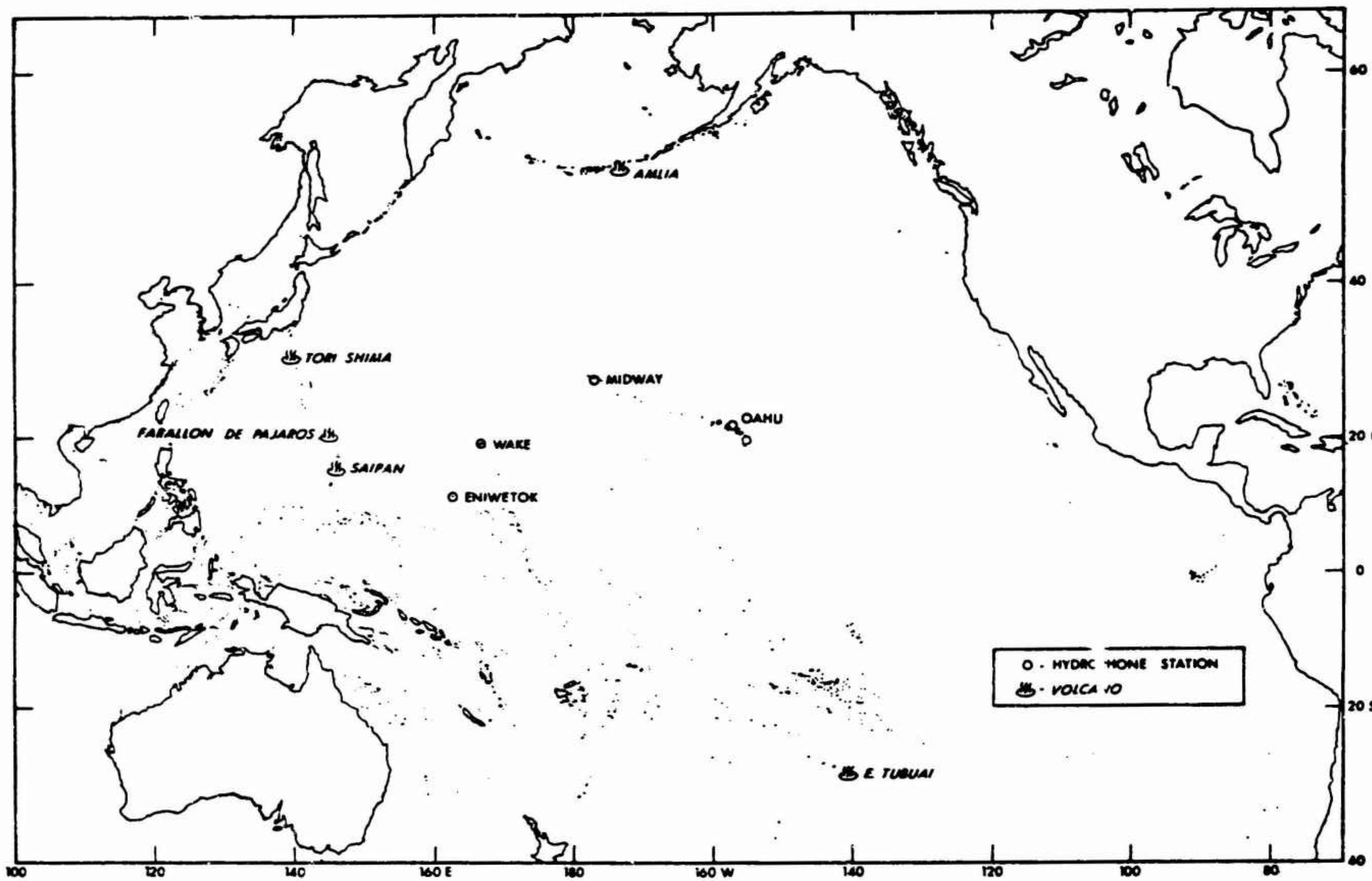

Fig. 1. Map showing the location of the five occurrences of submarine volcanic activity and the locations of four of the recording stations. Three other U.S. stations were used but are not shown.

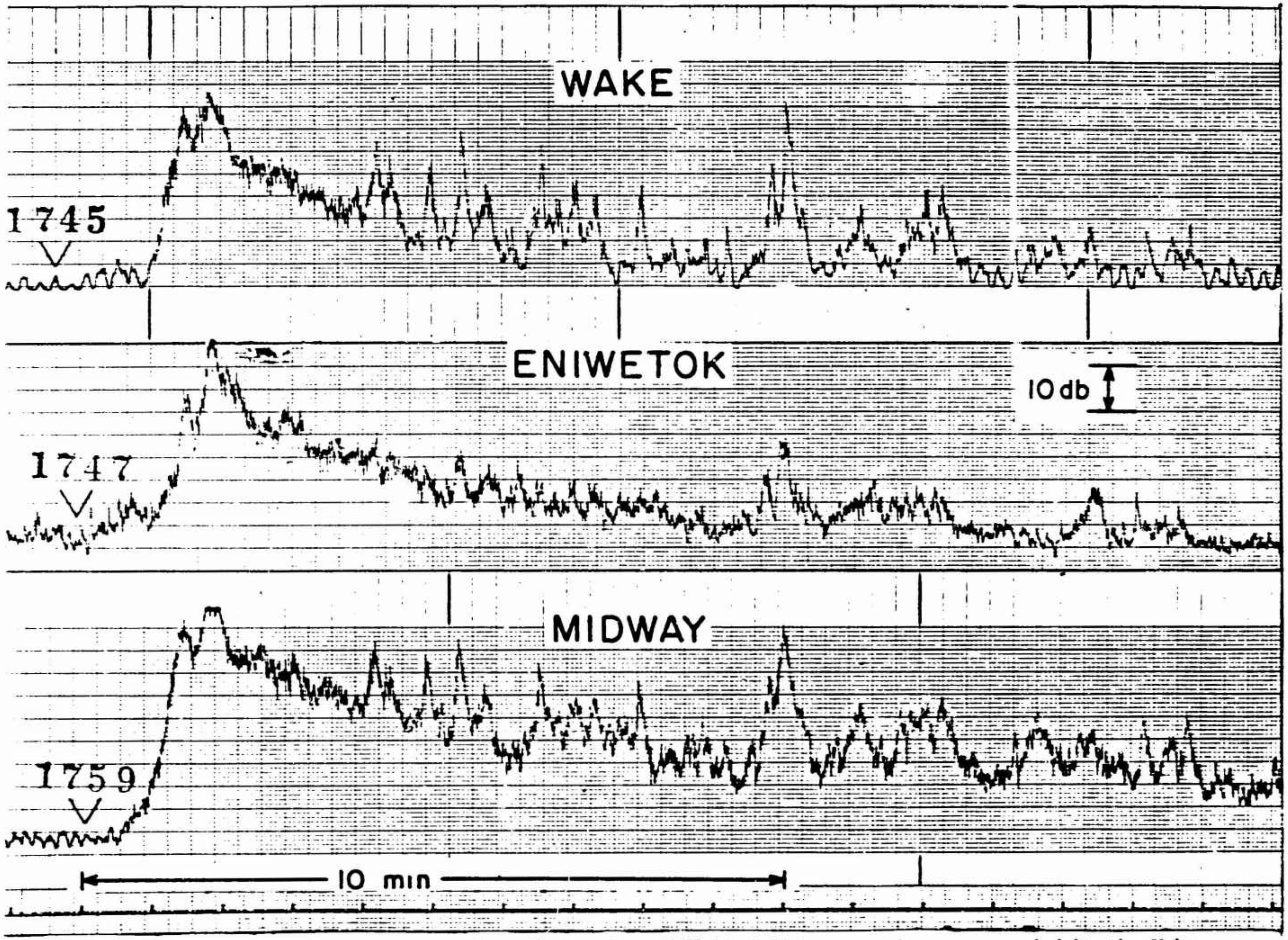

Fig. 2. Sound power-level record of the 12 - 14 November 1965 Tori Shima eruption as recorded by the Wake, Eniwetok, and Midway hydrophones.

Table 1. Occurrences of Submarine Volcanic Activity

Time	Place	Position	
12 - 14 November 1965	West of Tori Shima, Nanpo Shoto	30.7°N	139.8°E
April - May 1966	North of Saipan, Mariana Is.	15.6°N	145.9°E
27 March - 10 April 1967	Southwest of Farallon de Pajaros, Mariana Is.	20.4°N	144.8°E
July 1966 - beyond July 1967	Amlia Island, Aleutian Is.	52.0°N	173.5°W
29 May 1967	Southeast Austral Seamounts	28.8°S	140.5°W

After the first two hours, events began to thin out enough so that normal sea-noise background could be distinguished between them. Pacific T-Phase Sources for November 1965 lists 532 events between 1700 GMT 12 November and 1500 GMT 14 November for the Tori Shima region. Many more occurred for which good solutions were not obtained because of the difficulty of correlating events from station to station. The centroid of the 532 source locations, as indicated in Figure 3, lies some twenty-five nautical miles west-northwest of Tori Shima.

A histogram of the number of events located per hour for the first three days is given in Figure 4. The Seismological Bulletin of the U. S. Coast and Geodetic Survey lists five earthquakes at that location during that period; all of them occurred within the first two hours of the outburst of activity on 12 November 1965. The five events are listed in Table 2. The depths given are greater than we would infer from the sharpness of the peaks on the power level records. Deep events generally produce broad low T-phase peaks while shallow ones produce sharp peaks.

A United Press International report on 26 December stated "Tori Shima Island, situated about 400 miles south of Tokyo in the Pacific Ocean, started having tremors in mid-November, and its volcano erupted early this month. The meteorological agency evacuated its 52-man weather observation team from the island as a precautionary measure."

Table 2. Earthquakes listed by the Seismological Bulletin during the time covered by the histogram shown in Figure 4.

Time (GMT)* h	m	s	Lat. °N	Long. °E	Depth, km	Mag., CGS
17	13	58.3	30.7	139.9	100	4.5
17	14	21.3	30.7	140.0	85	5.3
17	52	27.6	30.7	140.1	65	6.2
18	15	17.0	31.5	140.3	169	4.6
19	04	39	31.5	140.6	33	4.7

* 12 November 1965.

According to Kuno (1962) Tori Shima is a stratovolcano of 403 meters height above sea level and 2.7 kilometers in diameter. The last activity listed was in 1939 when an eruption occurred in the central crater with explosions and a lava flow which lasted more than four months and produced a volume of 0.09 cubic kilometers. A previous eruption in 1902 killed about 125 persons. At that time two craters were formed and an estimated volume of 0.03 cubic kilometers of material was ejected. In addition, a submarine eruption occurred 1-1/2 kilometers southwest of the island. A region where there have been eight observations of submarine eruptions between 1672 and 1916 lies 40 to 50 nautical miles north of the 1965 underwater noise source. Figure 3 shows the location of the previously reported submarine eruptions.

SAIPAN

About the third week of April 1966, T-phase workers became aware of an unusual noise on the Wake and Eniwetok records. Fluctuations in the noise were correlatable between widespread hydrophones at each station and, upon further examination, were found to be correlatable between Wake and Eniwetok (Fig. 5). Sofar positions, computed by the T-phase source location program, were grouped about 15.6°N 145.9°E, which is about 20 nautical miles north of Saipan Island. The fluctuations of sound level were nearly periodic with a cycle length on the order of one minute, similar to the activity called "cycling" by Kibblewhite. However, the periods he observed north of New Zealand were longer, usually 3 to 5 minutes, and varied widely from one occasion to another.

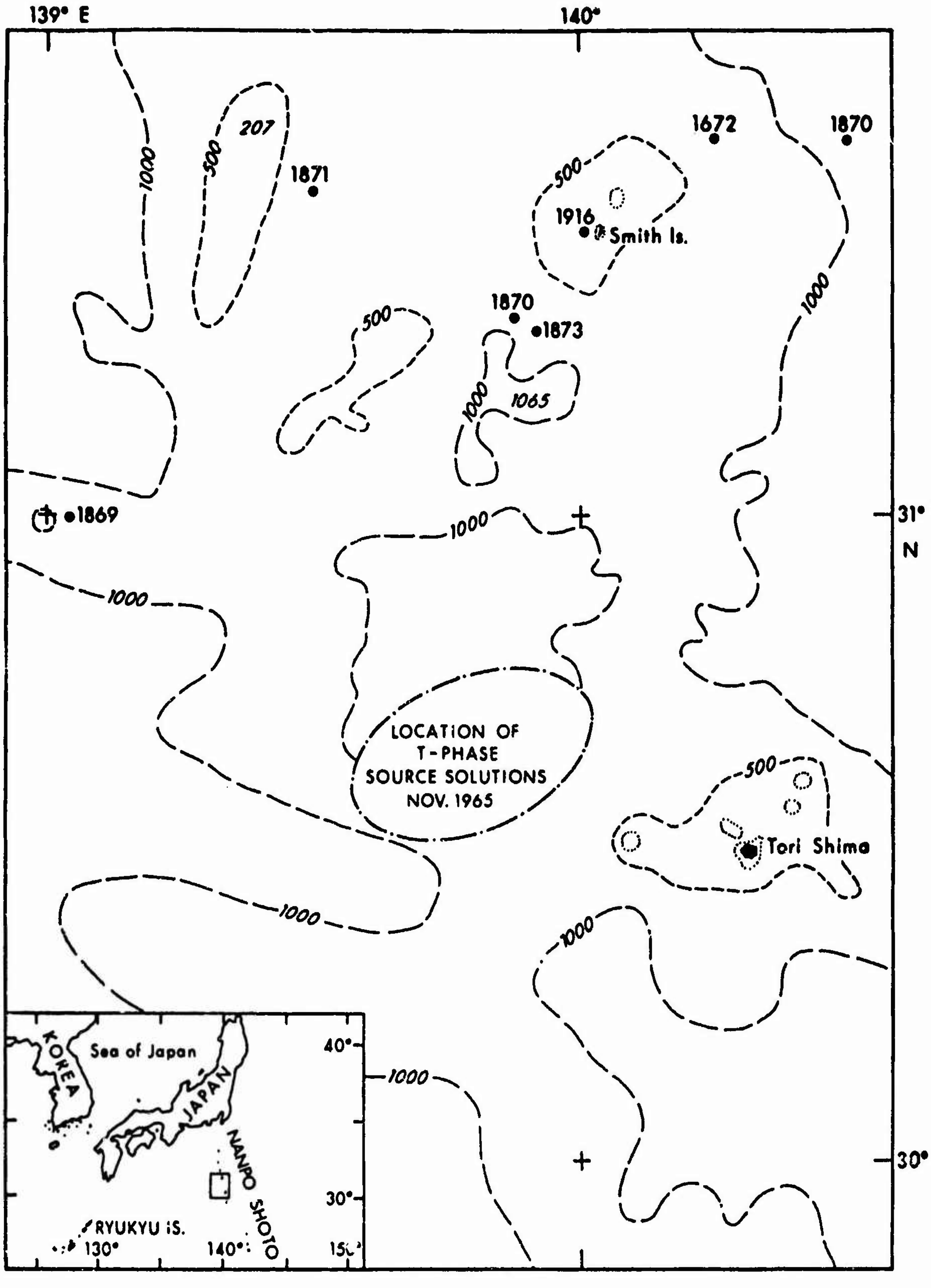

Fig. 3. Map of the Tori Shima region showing positions and years of previous observations of submarine eruptions and the distribution of the T-phase source solutions for November 1965. Inset map locates region.

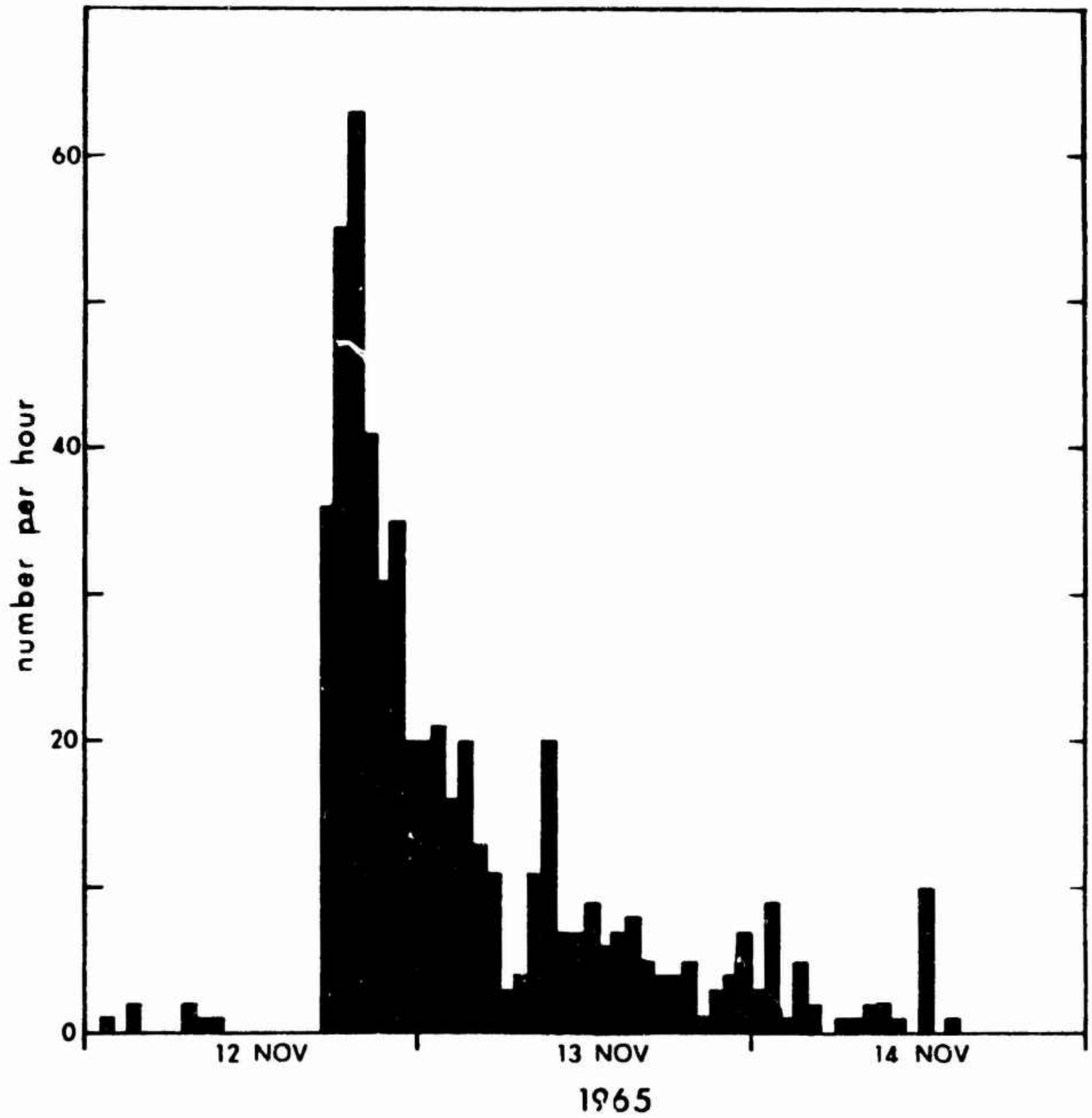

Fig. 4. A histogram of the number of $\underline{T}$ phases located per hour for the first 3 days of the Tori Shima eruption.

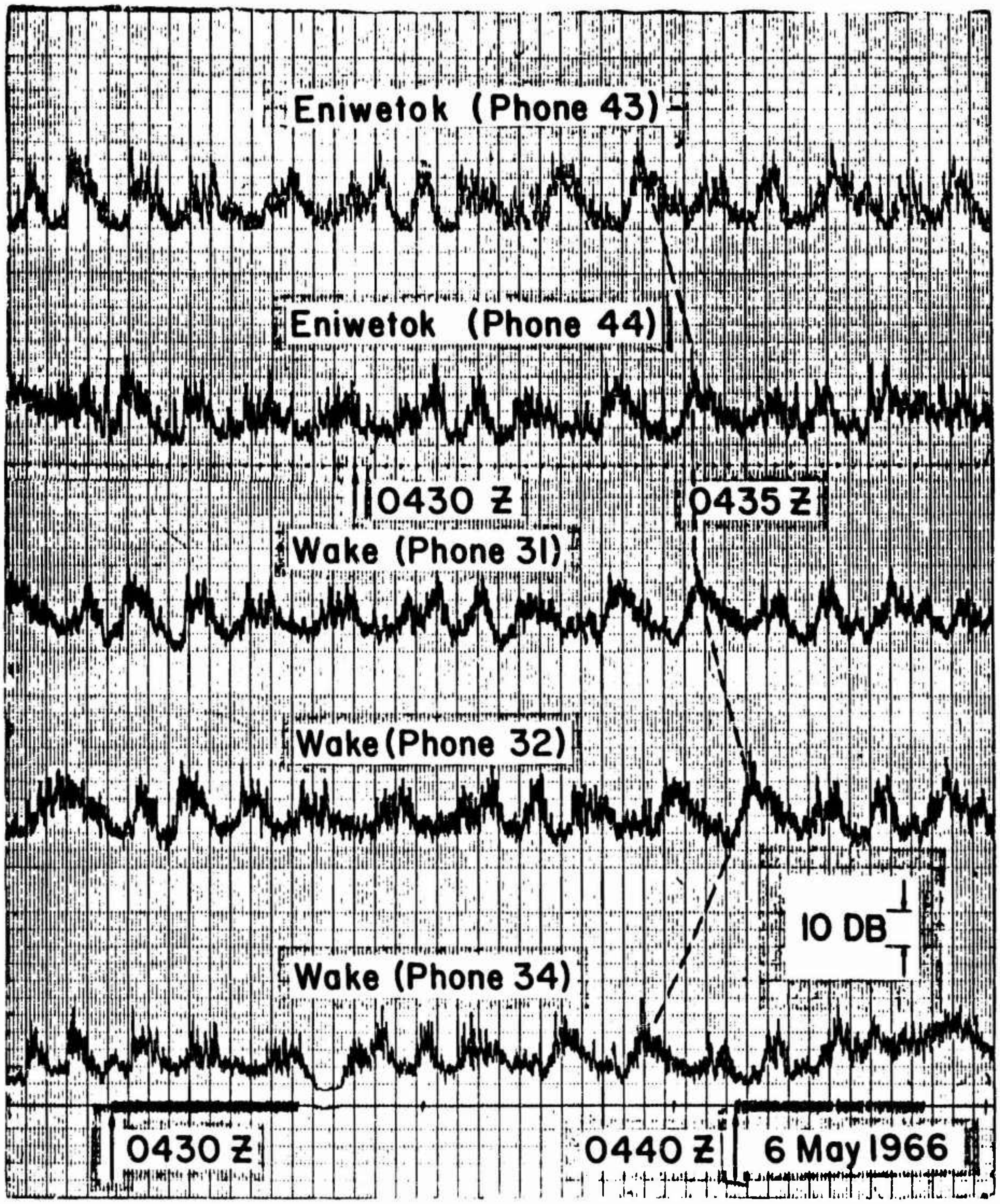

Fig. 5. Sound power-level records of the submarine eruption north of Saipan as recorded by the Wake and Eniwetok hydrophones. The dashed line connects correlated parts of the signal between hydrophones and stations.

The activity in the first month is represented by Figure 6; the "high" level is like that in Figure 5. Low-level activity and isolated noise spikes continued beyond July.

The Bulletin of Volcanic Eruptions reported only one eruption in the Mariana Islands for 1966 (the fishing boat Hinode Maru's observation of an explosive eruption on Pagan Island on 23 May). Pagan is three degrees north of Saipan. No indication of this subaerial eruption was found on the hydrophone records. The Bulletin also reports a submarine eruption on 14 April 1964 at 15°05'N 145°08'E, which is 35 nautical miles west of Saipan. A report attributed to the U. S. Navy said volcanic smoke rose out of the sea to a height of 2400 meters. No indication of this eruption was found on the Midway, Wake, and Eniwetok records. Probably the Wake and Eniwetok recording stations were shadowed by Saipan and Tinian Islands, and the Midway hydrophones similarly shadowed by Kure Island.

FARALLON DE PAJAROS

A two-week-long noise outburst in the Pacific, which masked other events on several hydrophone, began 27 March 1967 at about 1140 GMT. It continued without pause, gradually growing more intense until it ended rather abruptly on 10 April at about 0100 GMT. A playback of a magnetic tape at four times recorded speed sounded like the crump of distant artillery. Sound level records from four of the stations, recorded about an hour before the noise ended, are shown in Fig. 7. The high frequencies and the sharp peaks in the power level record suggest a very shallow source, even, perhaps, at the sea floor.

A sofar solution gave a position of 20.4°N 144.8°E, about 11 miles southwest of Farallon de Pajaros, also known as Uracas Volcano. According to Kuno (1962) it is a stratovolcano within an older, enlarged crater which has a history of "Strong Strombolian activity, whereby red hot lava fragments and lappili were ejected," for the years 1912, 1925, 1932, and 1936. "In 1934 a submarine eruption was seen near the main island at 20°31'N 144°53'E. Dark colored pumice was seen floating on the sea." A possible occurrence of explosive activity in 1953 is the last item which he listed.

AMLIA

During processing of the January 1967 records (power-level) we became impressed with the frequent occurrence of some explosion-like signals that had sources near the center of Amlia, one of the Aleutian Islands. Because of their appearance

on the records there was some doubt whether they should be categorized as earthquake T phases. Some examples are shown in Figure 8. The possibility that they were man-made explosions was discounted on the grounds that they were random in size and in time, and on the fact that during the winter high seas and freezing gusty winds discourage such work.

A histogram of the number of located Amlia events per day, Figure 9, shows the onset of this activity in July 1966 and its increasingly intense recurrences throughout the following 13 months. A list of C.&G.S. epicenters which correspond to T-phase source solutions is given in Table 3. The epicenters are plotted in Figure 10.

Table 3. C.&G.S. epicenters which correspond to T-phase source solutions at Amlia Island.

Date		GMT H M S	Lat., °N	Long., °N	Depth, km.	Mag., CGS
1966						
June	12	12 41 34	51.6	173.2	33	4.1
July	18	11 04 30	51.8	173.4	18	4.0
	19	19 20 33	51.7	173.3	47	5.5
	19	21 18 43	51.8	173.3	56	4.5
	20	07 58 12	51.7	173.3	38	4.4
	21	00 58 20	51.8	173.1	33	4.0
	22	10 17 23	51.7	173.5	56	5.6
	23	03 37 56	51.7	173.6	41	4.7
	23	04 09 36	51.9	173.4	33	4.2
	23	08 26 10	51.9	173.5	33	4.7
	23	12 21 57	51.7	173.4	21	4.4
	23	15 26 16	51.7	173.6	51	4.3
	23	20 12 00	51.8	173.5	36	4.9
	24	04 34 05	51.7	173.4	33	4.1
	26	12 50 19	52.0	173.5	36	4.8
Aug.		none				
Sept.		none				
Oct.	2	16 43 45	52.3	173.0	33	4.4
	8	17 43 56	51.6	173.8	35	5.5
Nov.		none				
Dec.	21	12 57 57*	52.2	173.7	33	4.0
	29	08 07 06	52.3	173.3	33	4.1
1967						
Jan.	14	17 24 02*	52.0	173.6	33	3.3
	15	08 42 50*	51.8	173.5	20	4.3
Feb.		none				
Mar.		none				

* These earthquakes produced strong sharp-peaked T phases.

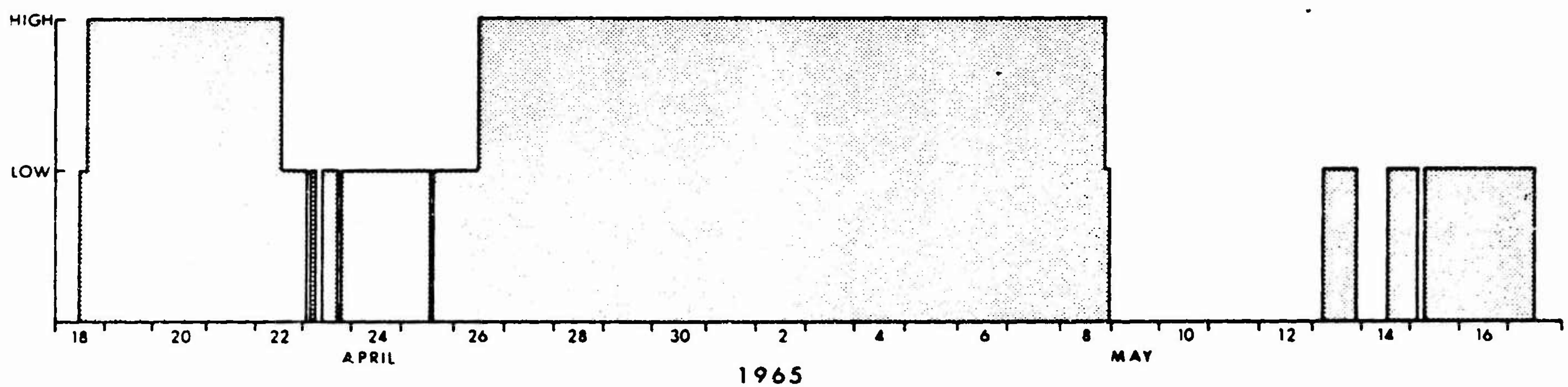

Fig. 6. Histogram of Saipan activity for the first month. "High" level is like that of Figure 5.

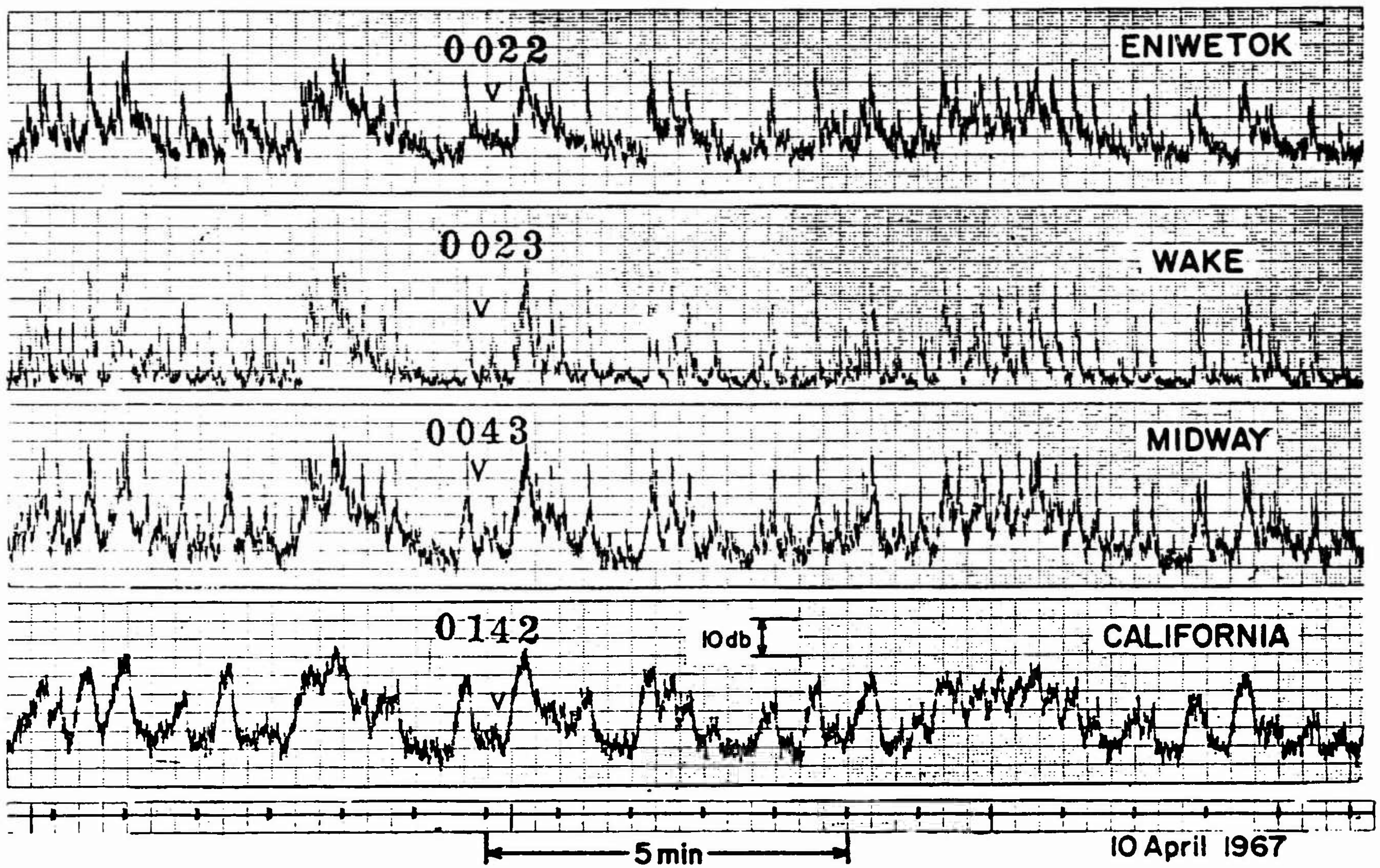

Fig. 7. Sound power-level records of the Farallon de Pajaros eruption about an hour before it ended.

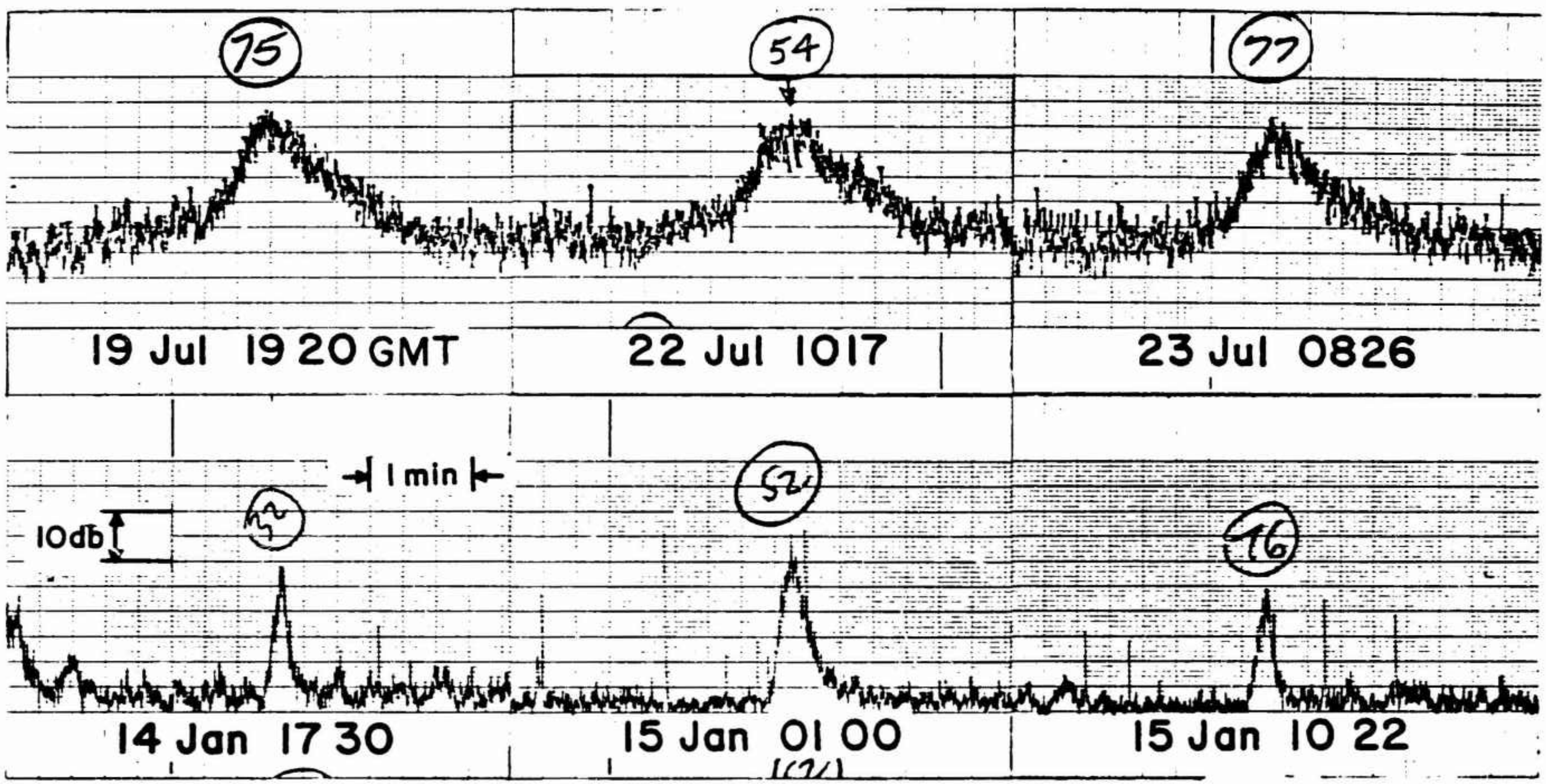

Fig. 8. Some examples of Amlia Island events. The earlier deeper events are above, the later shallow ones below.

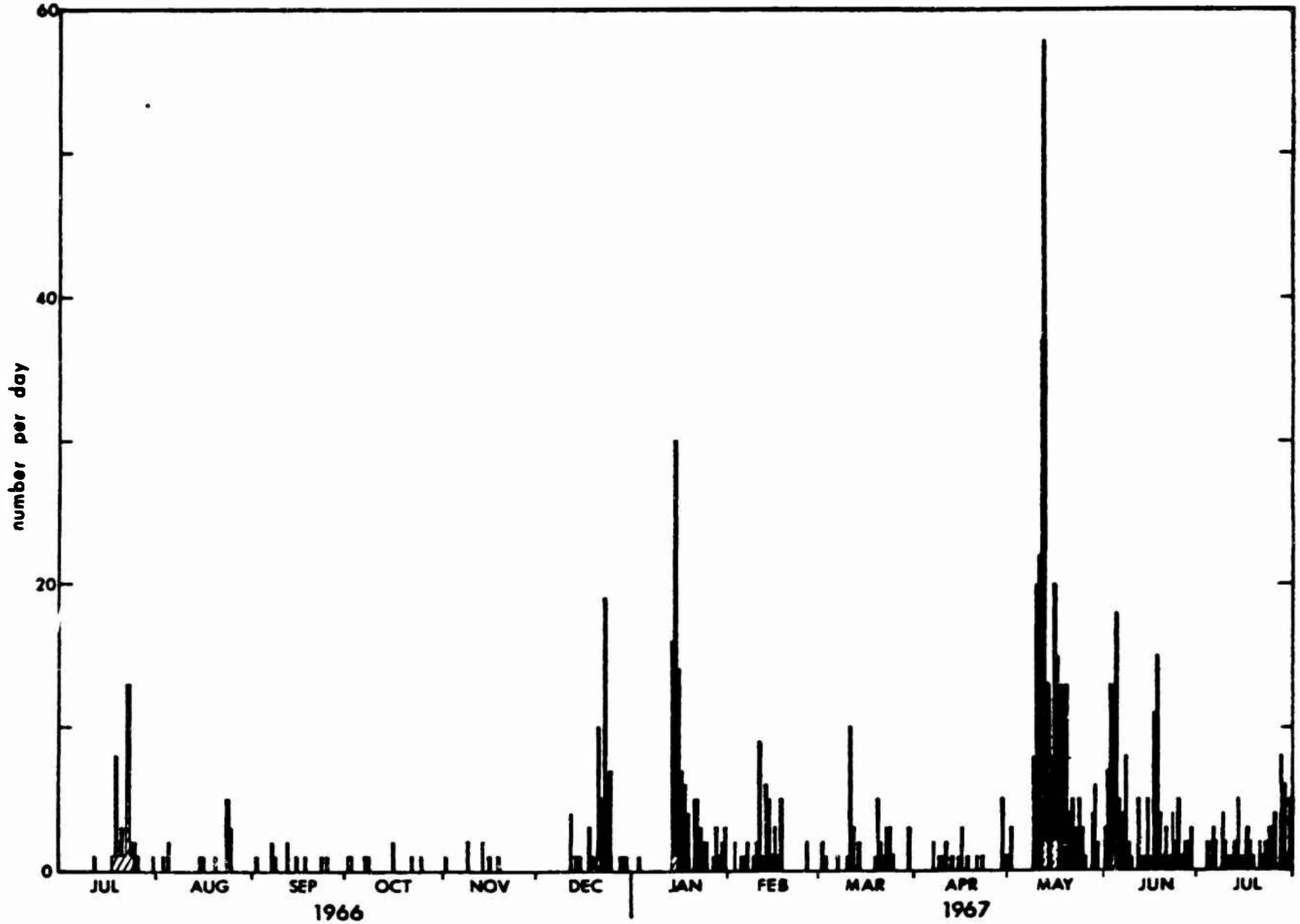

Fig. 9. Histogram of the number of Amlia Island events located per day: "black" - located by hydrophone system; "cross-hatched" - located also by seismometer network.

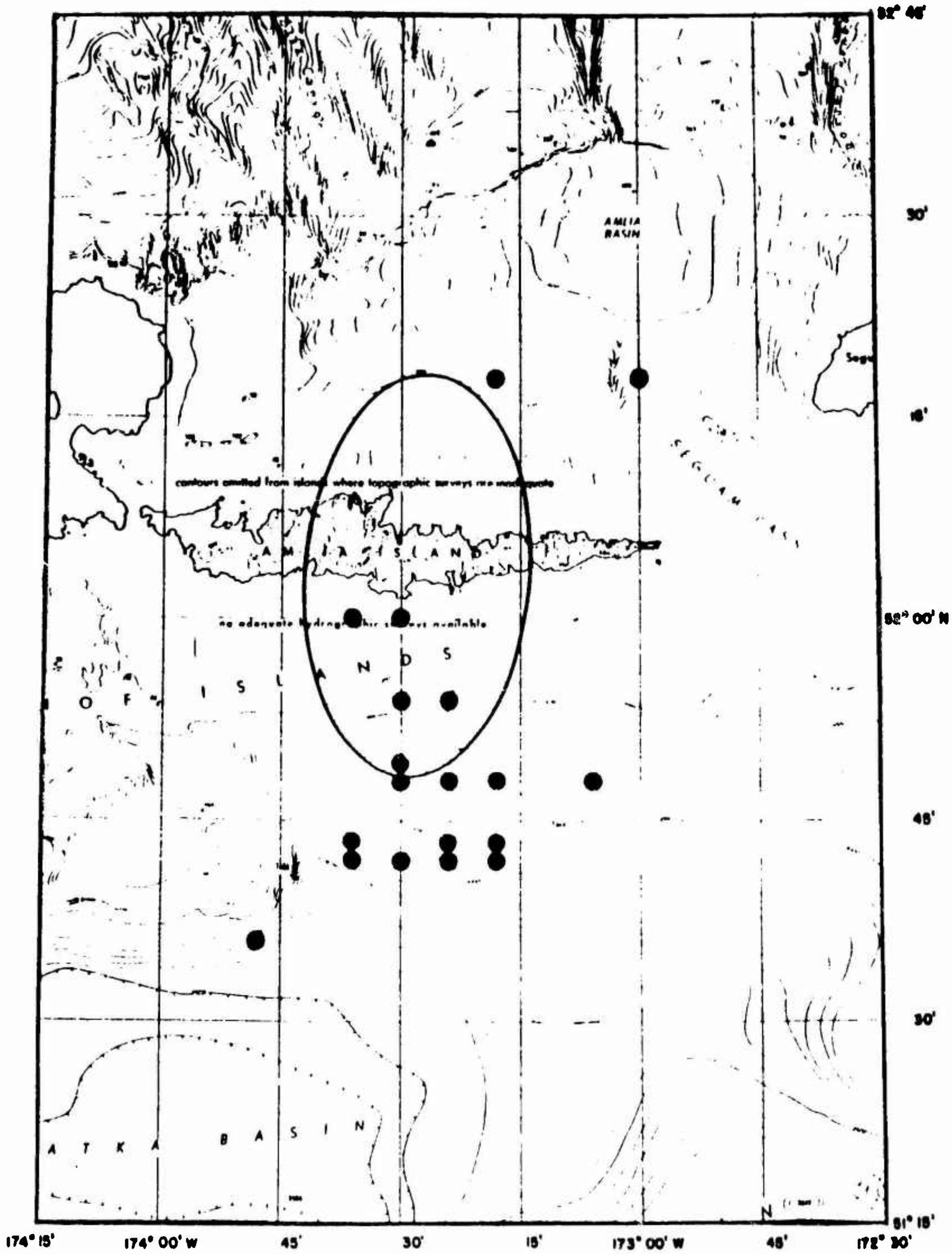

Fig. 10. Map of Amlia Island region showing T-phase source distribution (outlined area) and C.&G.S. earthquake epicenters (black dots).

A reexamination of the hydrophone records showed that the T phases from July through November all displayed the rounded power-level peaks which are characteristic of normal depth earthquakes. In December, however, the shape of the peaks changed abruptly to sharp, short duration, signals--which we ascribe to shallow sources. Only the three strongest of the sharp-peaked signals had a corresponding earthquake epicenter listed by the C.&G.S. The hypothesis, then, is that the activity began in July at normal depths and five months later broke out as a very shallow swarm of small quakes whose magnitudes were below the location threshold of the seismometer network. By contrast, the shallowness promoted strong T-phase generation.

A survey of the previous year in the C.&G.S. Seismological Bulletin showed that Amlia was relatively quiet, not exceeding 3 events per month.

There is no volcano charted on Amlia Island.

AUSTRAL SEAMOUNTS

On 29 May 1967, a 4-1/2 hour series of sharp-peaked noises from the South Pacific was detected. A portion of the series is shown in Figure 11. The average position solved for 12 different peaks was 28.8°S, 140.5°W--which is at the southeast end of the Austral Seamount Chain. The maximum deviations were $\pm 0.2^\circ$ latitude and $\pm 0.1^\circ$ longitude. The computed origin times fell between 0322 and 0758 GMT. It was immediately apparent from the spiked character of the power-level records that these were not ordinary earthquake T phases. Also, they bore no resemblance to man-made disturbances by reason of their randomness in size and time. The power-level records are similar to those of the Farallon de Pajaros series although the duration was much shorter. The magnetic tape playback (at four times recorded speed) sounded like the Pajaros series but of lower frequency, as is to be expected for this more distant source.

SONAGRAMS

The first four sonagrams (Figs. 12 through 15) are given as standards against which the eruption sonagrams may be compared. They contain an ordinary earthquake T phase, a T phase from a nearshore underground nuclear explosion, an underwater 5-ton explosion, and a 4-pound sofar bomb. (The T phase is here defined as that portion of the elastic energy from an underground event which propagates horizontally through the ocean.) The step-ladder markings on the left

side of the sonagrams are a frequency calibration. At this recording speed they represent eight 6 1/4 Hz steps, their width indicates the bandwidth of the sonagraph filter. The T phase (Fig. 12, top), recorded at Wake Island, was from an earthquake of magnitude 3.8, depth about 40 kilometers, situated about 130 kilometers behind the Kuril Islands at 46.5°N 148.1°E on 20 October 1963 at 0252 GMT. The nuclear explosion, recorded at Eniwetok, was Longshot (Fig. 12, bottom), an 80-kiloton blast contained underground at a depth of 2,300 feet on Amchitka Island in the Aleutians on 29 October 1965. The equivalent earthquake magnitude was between 5 and 6. (The vertical spike in the sonagram is due to a flaw in the magnetic tape.) The frequency distribution of the energy in the nuclear explosion T phase is similar to that of the earthquake T phase, but its time distribution is much more sharply peaked. We ascribe this to the shallow focal depth of the explosion. The 5-ton (nitramon) explosion (Fig. 13, top), recorded at Oahu, was fired at 1000-foot depth south of the Aleutian Islands at 50° 04'N 176° 53'E on 8 September 1967 at 2230 GMT as part of the Aleutian Islands Ocean-Bottom Seismograph Experiment. There is an instrument noise line at 7 1/2 Hz in the sonagram. The 4-pound (TNT) sofar bomb (Fig. 13, bottom) was fired at 3000-foot depth about one thousand nautical miles east-northeast of the recording station at Oahu. There is an instrument noise line at 30 Hz in the sonagram. The two underwater explosion sonagrams were deliberately held to the same scale as the other figures for direct comparison, even though the higher frequency portion of the signals is omitted. The underwater explosion energy is not concentrated at the low-frequency end of the spectrum as is the case in the earthquake and the underground nuclear explosion T phases. Also, the duration is short, and the closeness of the contours on the trailing edge of the signal show the abrupt cut-off which is characteristic of sofar propagation in contrast to underground events which are typically steepest on the leading edge, are of longer duration, and die out gradually.

The volcanic events begin with those at Amlia Island (Fig. 14, as recorded at Midway Island). The sonagrams of these events are strikingly similar to that of the nearshore underground nuclear explosion on Amchitka Island, which is also in the Aleutians, and differ from the earthquake T phase in that they are of short duration with rapid onset and decay. We hypothesize that the Amlia events are T phases of shallow volcanic earthquakes from a submarine eruption just north of the island (there are no volcanoes charted on Amlia Island). This accounts for the combination of the short ground path evidenced by the short duration and the rarity of this type of T phase elsewhere in the Pacific. Also, they are similar in duration and spectrum to the earthquakes preceding the Tori Shima eruption (Fig. 15).

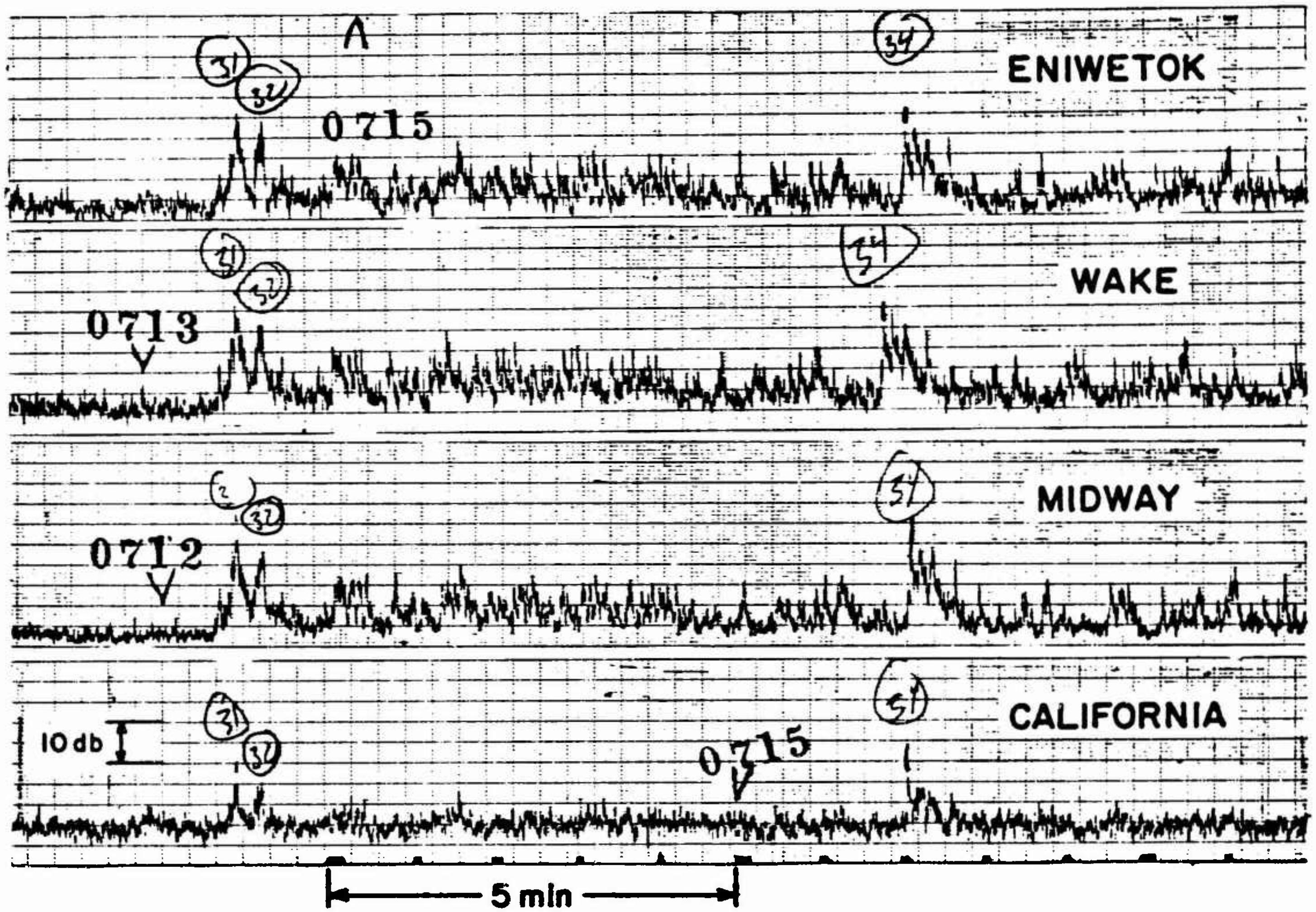

Fig. 11. Sound power-level record of the 29 May 1967 Austral Seamounts eruption near its beginning, as recorded by the Eniwetok, Wake, Midway, and California hydrophones.

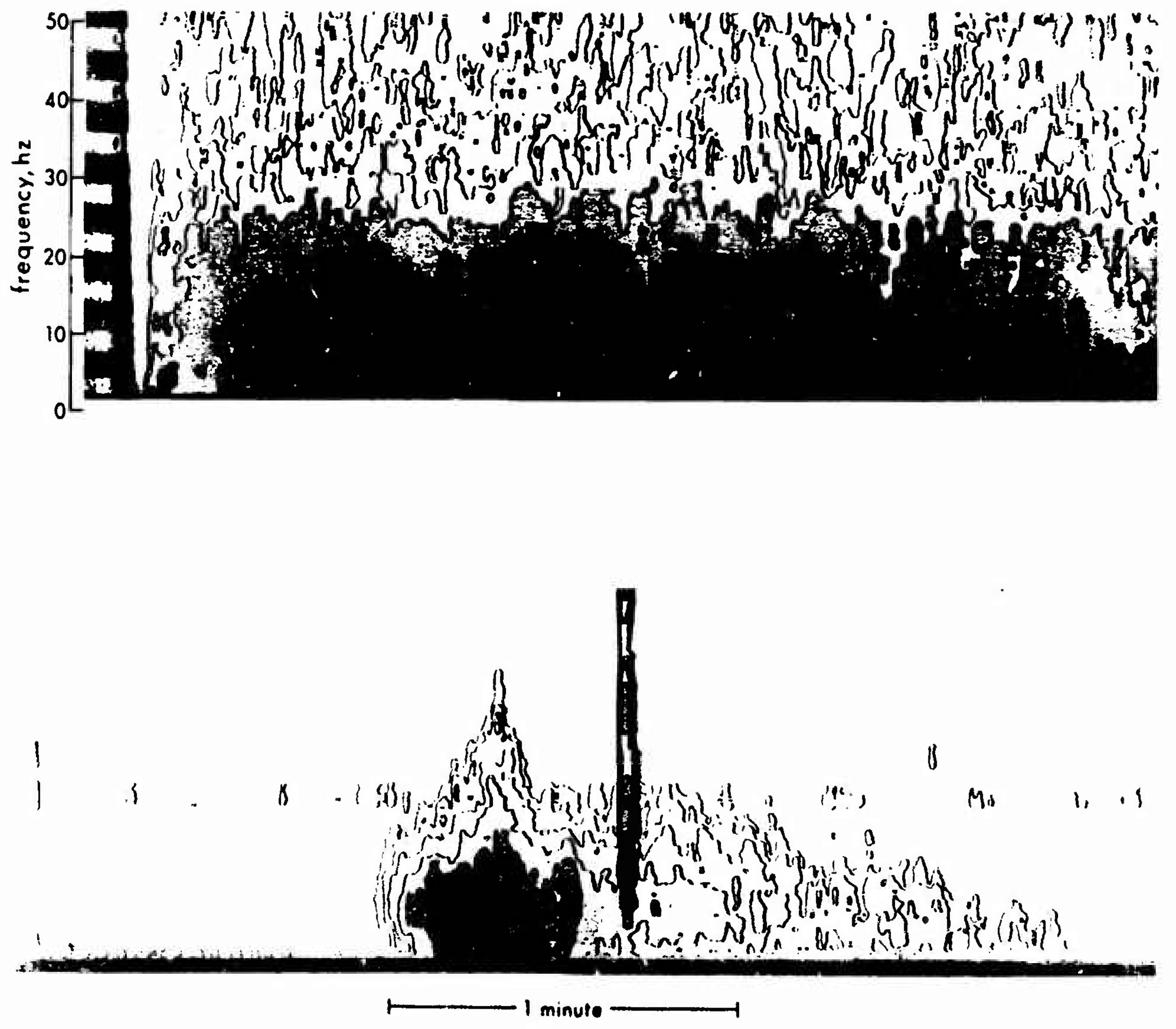

Fig. 12. Upper: T phase from a magnitude 3.8 earthquake 0 kilometers deep and 130 kilometers behind the Kuril Islands. It was recorded at Wake Island.

Lower: T phase from an 80-kiloton nuclear explosion located 2300 feet underground on Amchitka Island--equivalent to an earthquake of magnitude 5 - 6. It was recorded at Eniwetok. The vertical spike is due to a flaw in the magnetic tape.

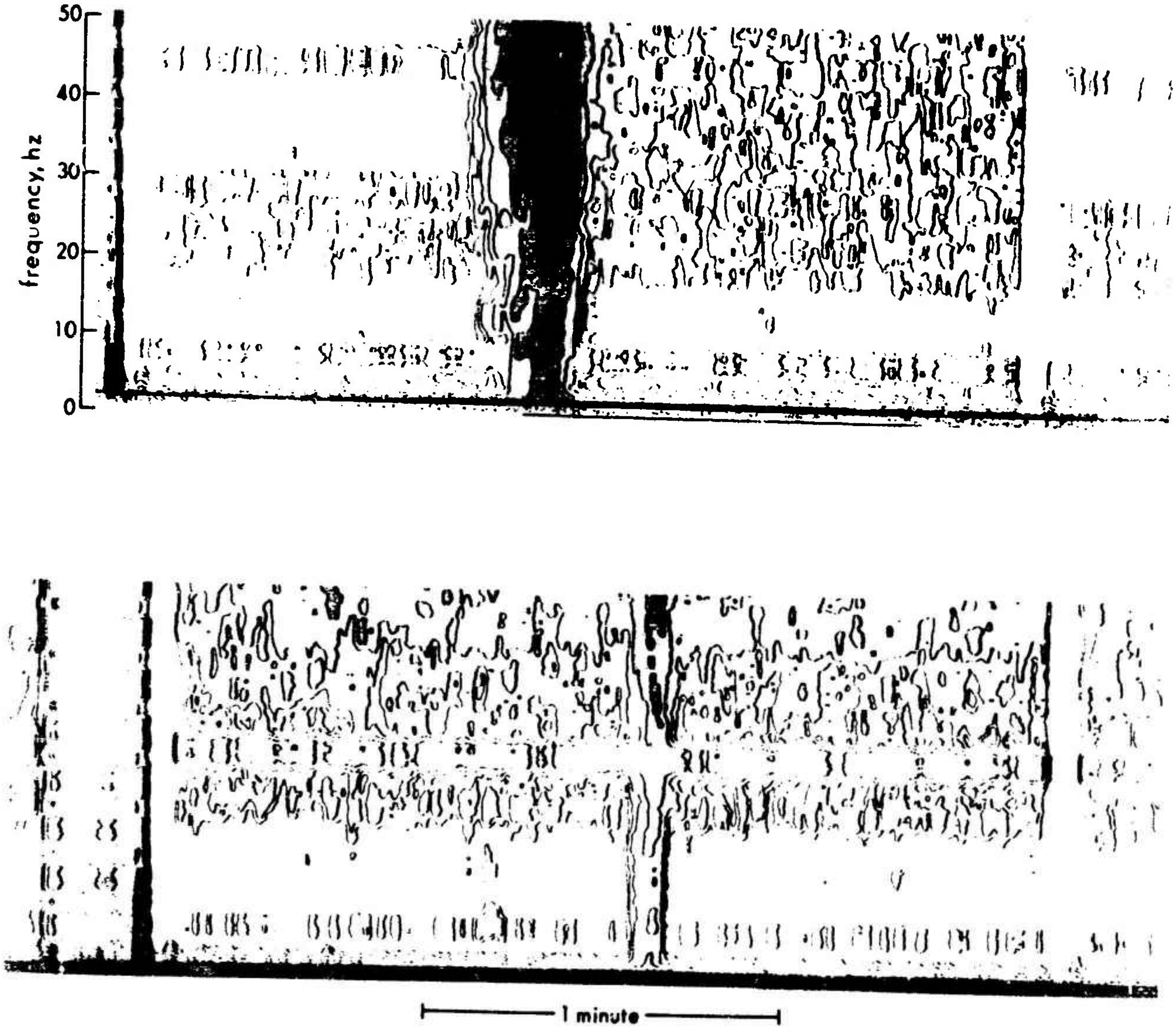

Fig. 13. Upper: 5-ton explosion 1000 feet under water south of the Aleutian Islands (recorded at Oahu). There is an instrument noise line at 7 1/2 Hz.

Lower: 4-pound explosion 3000 feet under water about a thousand miles east-northeast of the recording station on Oahu. There is an instrument noise line at 30 Hz.

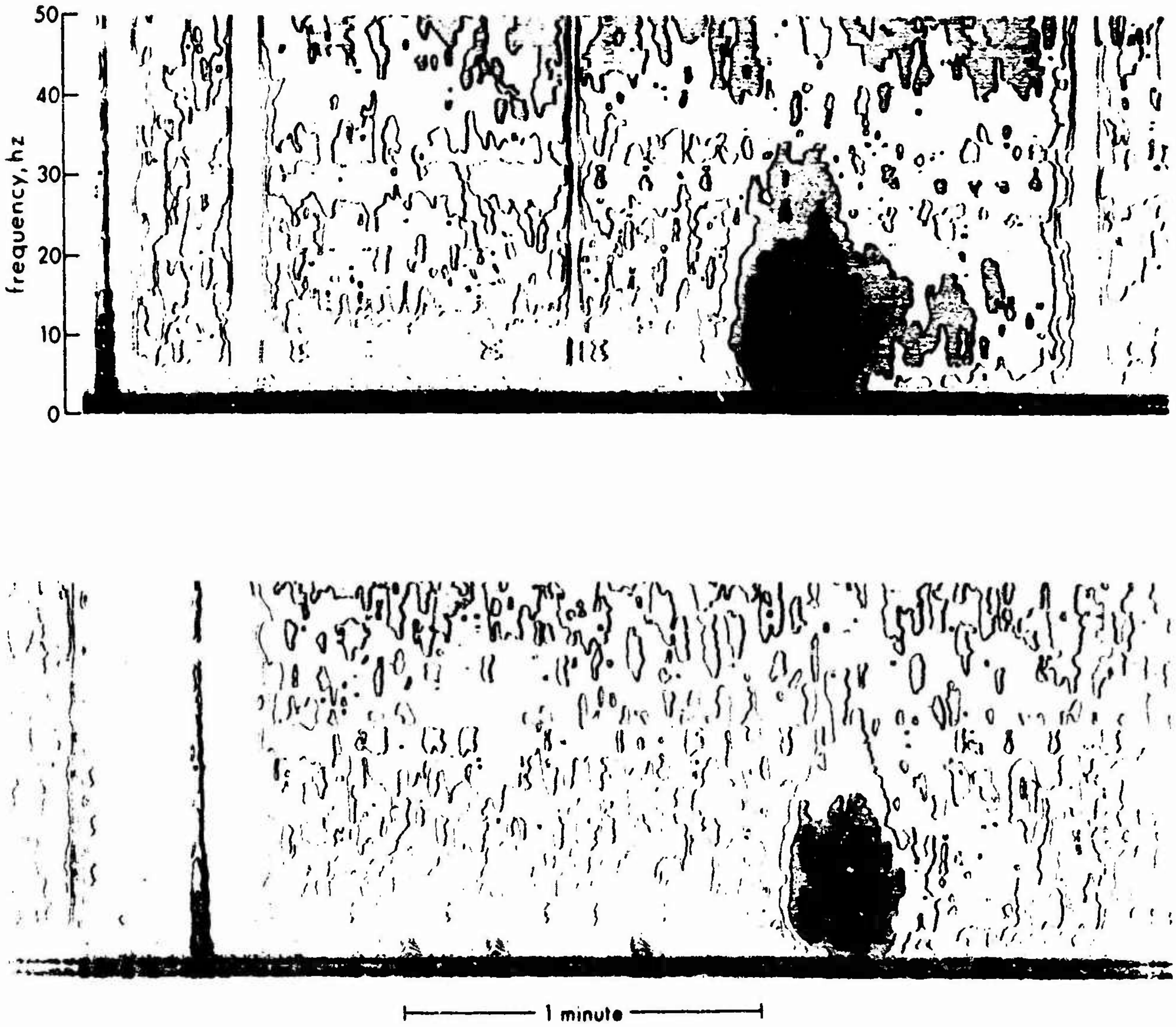

Fig. 14. Two Amlia Island events recorded at Midway. They are interpreted to be shallow volcanic earthquakes, too small to be located by the seismometer network. There is an instrument noise line at 7 1/2 Hz in both sonagrams, and three signal drop-outs in the upper sonagram.

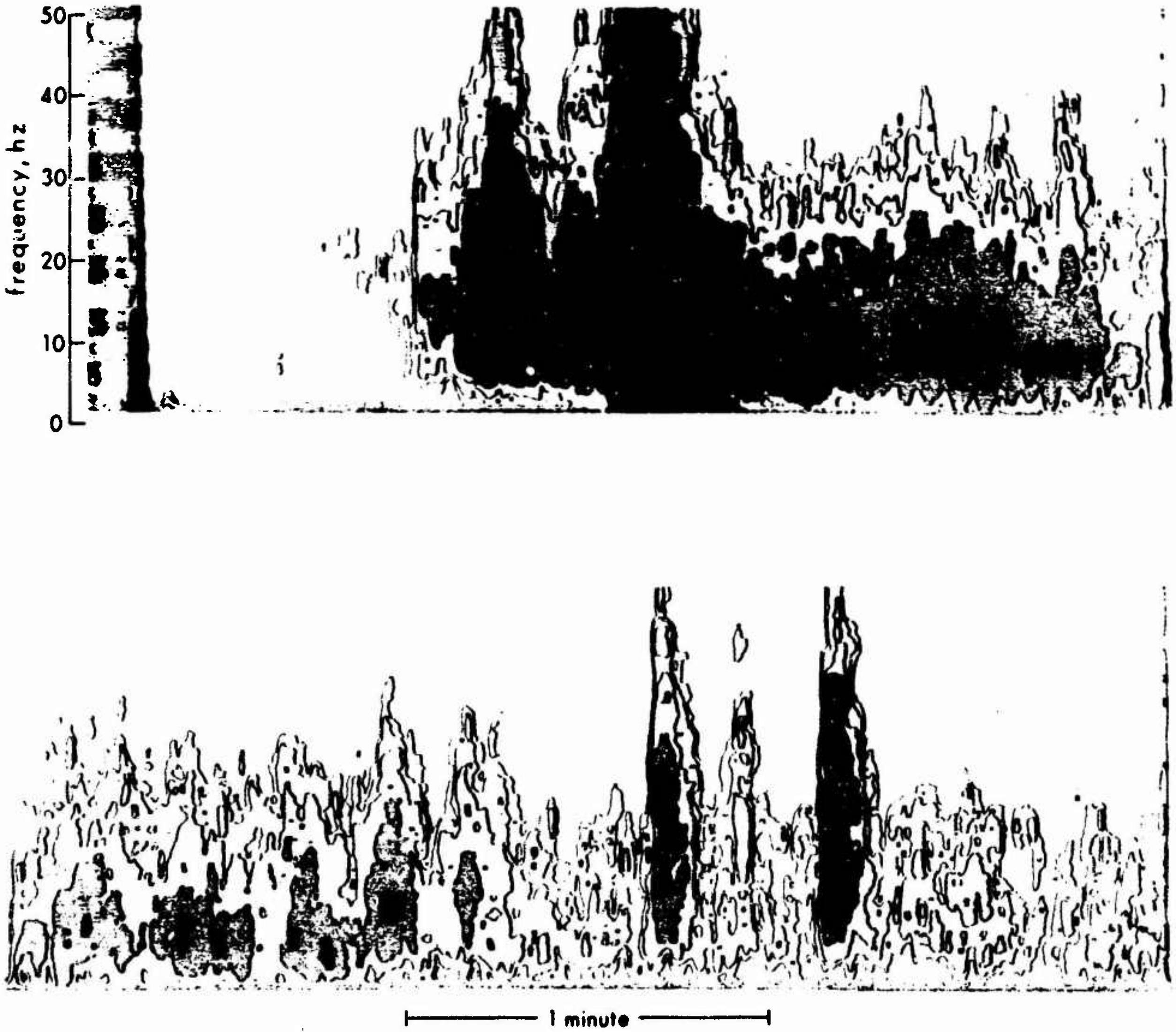

Fig. 15. The start of the submarine eruption near Tori Shima. The two sonagrams span a continuous time interval. The activity began with two earthquakes (upper) of magnitude 4.5 and 5.3. Impulsive events (lower), thought to be volcanic explosions, then began. They were recorded at Wake Island.

The start of the submarine eruption near Tori Shima as shown in Figure 15 was recorded at Wake Island. The two sonagrams span a continuous time interval and have a ten-second overlap. The large events on the top half of the figure were reported as earthquakes of magnitude 4.5 and 5.3 by the C&GS and their source data are given in Table 2. However, the depths of 100 kilometers and 85 kilometers computed by C&GS seem excessive since their sonagrams compare most closely to that of the very shallow nuclear explosion and are of shorter duration than T phases of even "normal" (nominally, 33 kilometers) depth earthquakes. The bottom half of the figure shows the beginning of a long train of impulsive events which are interpreted as volcanic explosions within the magma conduit.

The eruption near Farallon de Pajaros (Fig. 16, as recorded at Wake Island) and the Austral Seamounts eruption (Fig. 17, as recorded at Midway Island) show the same pattern of a swarm of impulsive events. These events have the short duration of underwater explosions but their energy is in the lower frequencies like that of the underground events--in support of the hypothesis that they are volcanic explosions within the magma conduit.

Spectral bands occur in the Austral Seamounts sonagram at 11 and 22 Hz, and an instrument noise line occurs at 30 Hz. Spectral bands also occur in the eruption near Saipan (Fig. 18, as recorded at Wake Island) at 10 and 21 Hz, and in the bottom sonagram at 31 Hz. Our distinction between instrument noise lines and spectral bands in the eruption is based on the continuity of the former and the strongly fluctuating intensity of the latter. The spectral bands in the eruption signal might be caused by resonances in the magma conduit.

DISCUSSION

We have mentioned, in several instances, our interpretation of sharp-peaked power-level records as indications of shallow earthquake foci. Such a relationship for abyssally generated T phases has been treated (Johnson et al., 1967), and the extension to slope-generated T phases may follow somewhat the same arguments. Although no thorough study has been carried out on the subject, it is a matter of experience that very deep earthquakes have broad, long-duration, T phases. At the other extreme, the Longshot nuclear explosion, detonated underground on Amchitka Island, produced a very sharp T phase. The great majority of T phases, which we assume to come from normal depth earthquake, have rounded peaks.

The rarity of acoustic signals from submarine eruptions contrasted with the tens-per-day frequency of earthquake T phases shows a need for caution in interpreting discrete low-frequency signals as eruptions. For example, the Kandavu Island signals recorded by Kibblewhite (1966), which he described as low-frequency rumbles and called "eruptions", give every appearance of being ordinary earthquake T phases. Indeed, there is little reason to suppose that the rumbles heard aboard the TUI while anchored on the Kermadec Ridge were not ordinary earthquake signals. It would seem difficult to place a hydrophone in such a seismically active region and not record at least one earthquake in a reasonably short time (Sykes, 1966).

The spectra of signals reported here may be put into two categories, (1) those similar to tectonic, slope-generated, earthquake T phases (low frequency) and (2) those of distinctly higher frequency. Signals in the Amlia sequence and some in the Tori Shima sequence are in the first category. These are probably the T-phases of volcanic earthquakes. Such signals might be expected from both subaerial and submarine eruptions. The absence of a volcano on Amlia Island together with the propensity for Aleutian volcanoes to lie on the north side of the island chain (Coats, 1962), leads us to speculate that an underwater eruption was in progress north of Amlia. The known accuracy of our sofar locations in this region precludes the possibility that the signals could have come from either of the adjacent volcanoes. Of passing interest is Amlia Basin, a nearly enclosed depression, about 30 kilometers in diameter, lying north of the eastern tip of Amlia Island (Fig. 10). Although one may speculate that this basin marks the location of a former volcano, it also appears to be too far east to be the site of the present activity.

The seismic pattern of the Amlia events is similar in several ways to a model of the volcanic process as described by Eaton (1962) for the Island of Hawaii. In Eaton's model, magma is derived from a zone at least 60 kilometers deep. Swarms of deep earthquakes outline the position of the zone. Magma from the deep source streams slowly upward and collects in a shallow reservoir a few kilometers beneath the vent. Gradual over-filling of the reservoir causes failure of the enclosing rocks, resulting in earthquakes. Magma-split fissures are accompanies by swarms of small quakes until they reach the surface when the quakes abruptly cease and harmonic tremor begins as lava is emitted.

In the Amlia Island sequence no abrupt termination of the sharp-peaked events occurred. However, the transition from deeper earthquakes in July to shallower earthquakes in December apparently did take place. It may also be noted from Table 3 that the epicentral region shifted from south of Amlia in July toward the north in following months. his supports our speculation of a submarine vent north of Amlia.

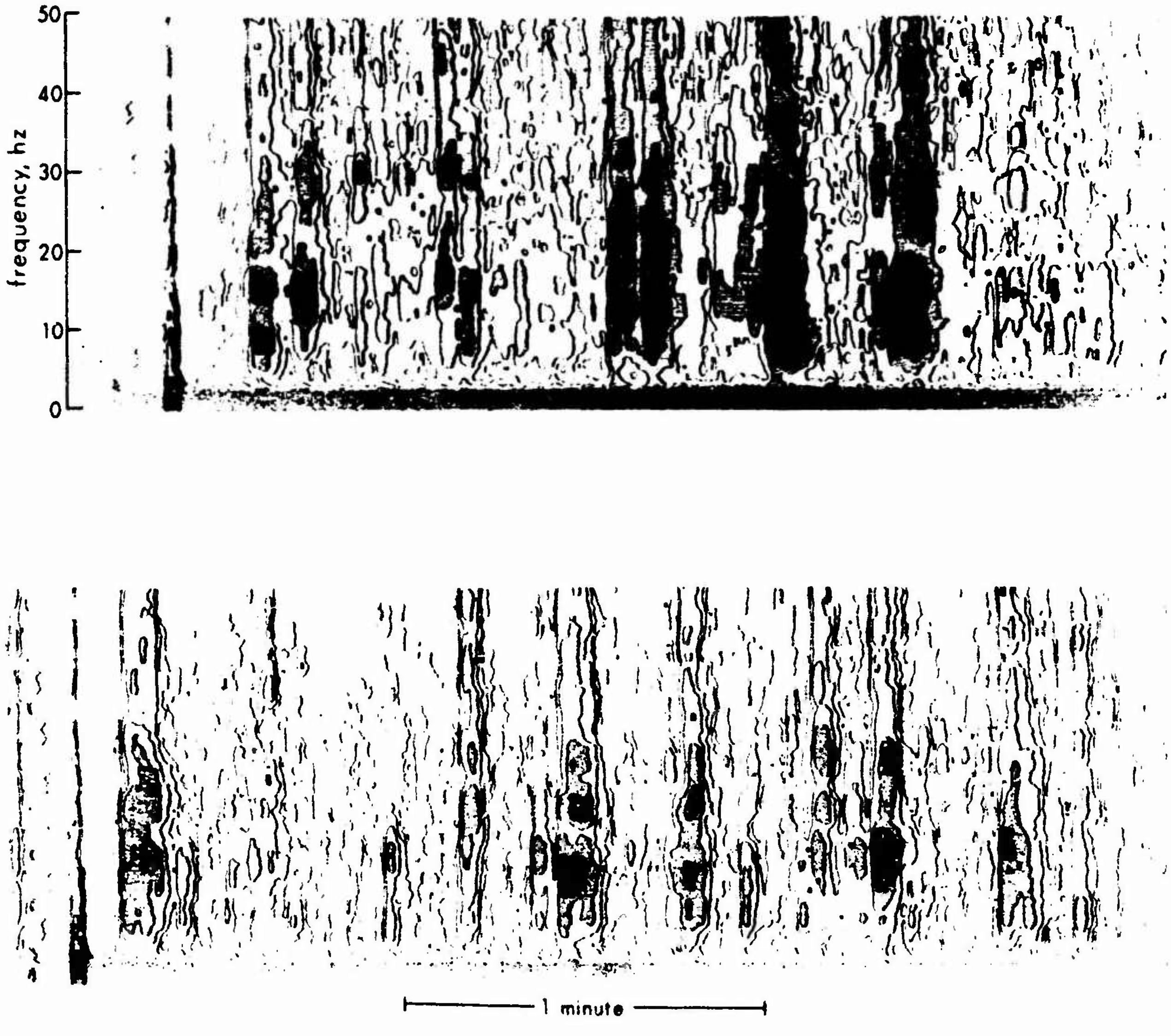

Fig. 16. Two sonagrams typical of the submarine eruption near Farallon de Pajaros as recorded at Wake Island.

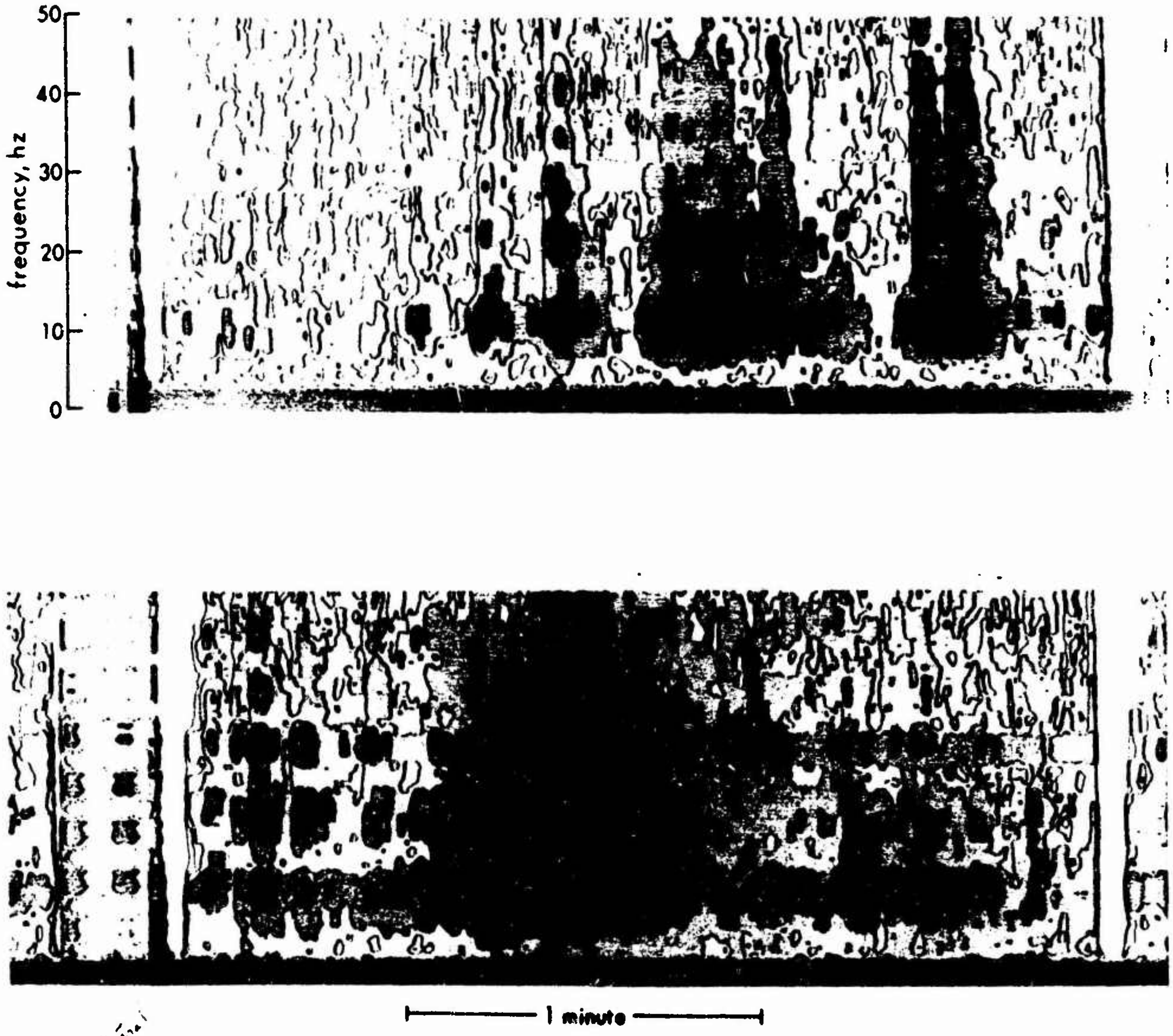

Fig. 17. Two sonagrams typical of the Austral Seamounts eruption as recorded at Midway. Spectral bands occur at 11 and 22 Hz. There is an instrument noise line at 30 Hz.

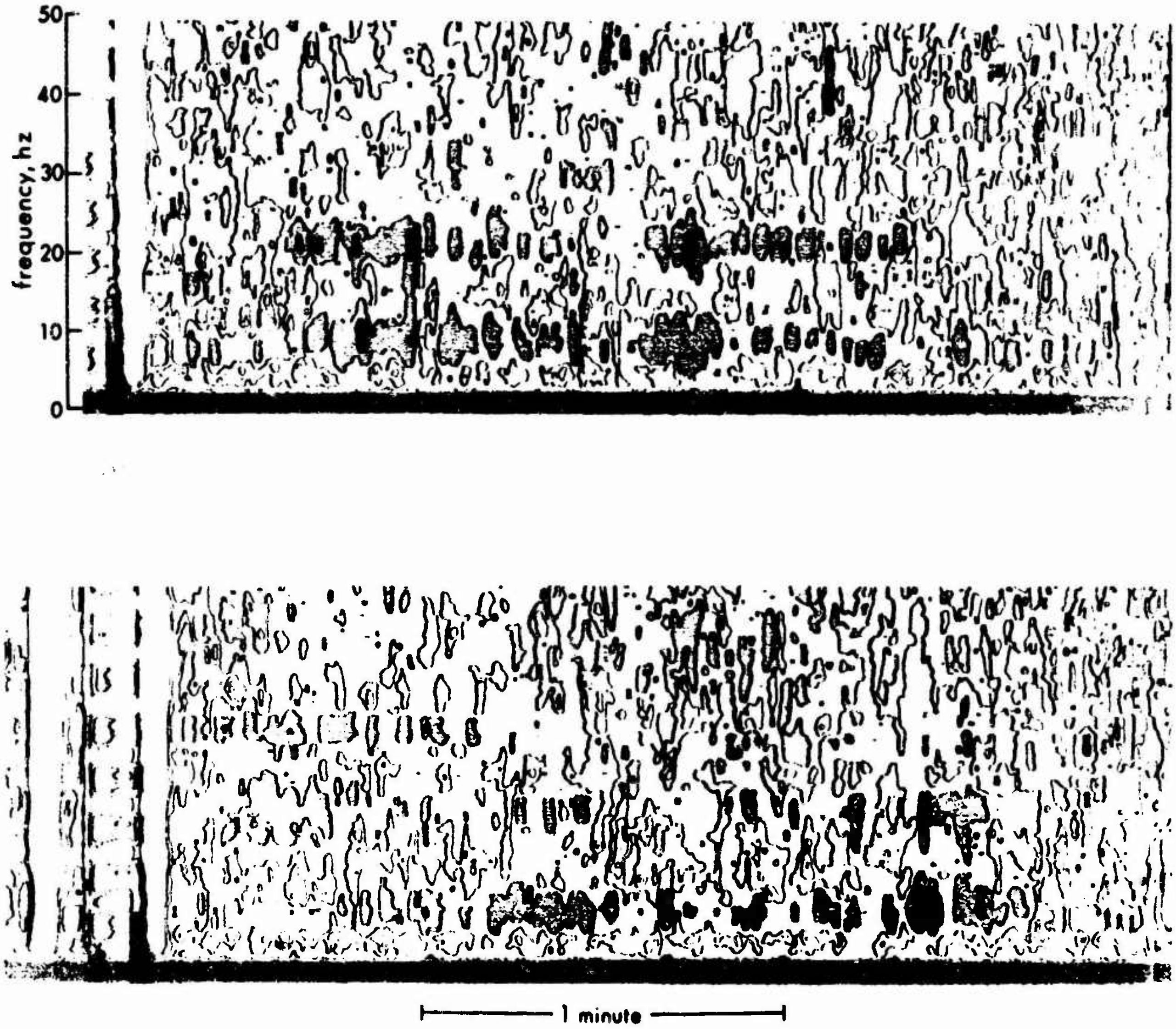

Fig. 18. Two sonagrams typical of the submarine eruption near Saipan as recorded at Wake Island. Spectral bands occur at 10 and 21 Hz, and in the bottom sonagram at 31 Hz.

Volcanic noise in the higher frequency category, such as observed from Saipan, Farallon de Pajaros, Austral Seamounts, as well as Tori Shima, is probably associated with the flow of magma into the ocean. This category of noise is more continuous although fluctuating in level. Of special interest are the bands in the spectra of the Saipan and Austral Seamounts eruptions. The Austral Seamounts eruption was sampled throughout its length and it was seen that after the first two hours, the position of the bands in the spectrum did not change with time. The possibility that the bands are due to bubble pulsation, as in underwater explosions, is eliminated by the constancy of their frequencies despite wide variation in signal strength. A more probable mechanism is that suggested by Richards (1963): a resonance within the conduit through which magma is released to the ocean.

Menard (1964, p. 79) cites the Austral Seamounts Chain, with its intermingling of guyots and islands, as an exception to the general pattern of island groups with atolls at one end and active volcanoes at the other. Our detection of what appears to be active vulcanism at the southeast end of that chain should help to restore the pattern.

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Five sources of underwater sound having volcanic characteristics have been located in the Pacific Ocean by means of the Pacific Missile Range sofar hydrophone network. Two are in the Mariana Islands, one in the Nanpo Shoto, one in the Aleutian Islands, and one at the southeast end of the Austral Seamounts. The sounds range in duration from a few seconds (explosive) to weeks (periodic low rumblings). Sonagrams of some of these events show multiple bands as do those of underwater explosions.

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